SEP 27'48 - 117

Volume 18 AUGUST, 1948 Number 2

Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
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« CONTENTS »

Environmental Significance of Dwarfed Faunas. A symposium ..... *Foreword by the Editor* 51

Dwarfed Protozoan Faunas ..... *Cecil G. Lalicker* 51

Assemblages of Diminutive Brachiopods and their Paleoecological Significance ..... *Preston E. Cloud, Jr.* 56

Environmental Significance of Dwarfed Cephalopods ..... *Bernhard Kummel* 61

Significance of Crustaceans in Dwarfed Faunas .. *Harold W. Scott* 65

The Use of Peels in Carbonate Petrology ..... *Edward J. Buehler* 71

Sediments from Pre-Cambrian Rocks of Southern Sangre de Cristo Mountains, New Mexico ..... *Raymond Sidwell and John L. Haliburton* 74

Sediments of Oki Bank in the Japanese Sea ..... *Hiroshi Niino* 79

Itabirite of Minas Geraes, Brazil ..... *Stanley A. Tyler* 86

REVIEWS

V. L. Bossazza. *The Petrography and Petrology of South African Clays, 1946* ..... *W. H. Twenhofel* 88

Chambers, *Mineralogical Dictionary, 1948*.. *W. H. Twenhofel* 88

Journal of Sedimentary Petrology

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Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

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Volume 18 AUGUST, 1948 Number 3

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CONTENTS

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 18, NO. 2, PP. 51–55
PLATE 1, FIG. 1, AUGUST, 1948

ENVIRONMENTAL SIGNIFICANCE OF DWARFED FAUNAS. A SYMPOSIUM

Foreword by the Editor

The four papers which immediately follow were presented as parts of a symposium on the "Environmental Significance of Dwarfed Faunas" in connection with the annual meeting of the Society of Economic Paleontologists and Mineralogists in Denver, Colorado, in late April, 1948. A fifth paper by Dr. H. B. Stenzel of the Bureau of Economic Geology, Austin, Texas, has not been received as the material for the August number of the *Journal of Sedimentary Petrology* is sent to press. It is hoped to present Dr. Stenzel's paper in a later number of the *Journal*. The several papers indicate the extent of knowledge relating to dwarfed faunas and the serious possibility of misinterpretation of an association of immature specimen as having the significance of a dwarfed association.

DWARFED PROTOZOAN FAUNAS

CECIL G. LALICKER
University of Kansas, Lawrence, Kansas

ABSTRACT

It is believed dwarfed protozoan faunas are caused by variations in the kind and amount of food, temperature of the water, chemical composition and physical conditions of the water, hydrogen-ion concentration, and light. Studies and experiments of the effects of variations of these factors upon the size and shape of living protozoans are discussed. Several dwarfed foraminiferal faunas are described.

Dwarfed protozoan faunas have been observed in rocks of different geologic ages at many localities. Although it is sometimes difficult to determine the exact cause of the dwarfing of any particular protozoan fauna, there are several variable factors in any environment which are usually operative upon the development of individual animals and populations. They are: (1) the kind and amount of food, (2) temperature of the water, (3) chemical composition and physical conditions of the water, (4) hydrogen-ion concentration, and (5) light.

Studies of the effects of variations of these factors upon the size and shape of living protozoans make possible intelligent speculations on the causes of dwarfed faunas in geologic formations. Ecological studies now in progress by Phleger, Stetson, and Trask of hundreds of cores and samples taken in the Gulf of Mexico should add much valuable information on the effects of variations of these factors.

FOOD. Differences in size, shape, and structure of certain living protozoan species are caused by differences in the kind and amount of food. Such observations have been made possible by experi-

ments with bacteria-free cultures during recent years. The number of protozoans in a natural habitat is largely influenced by the food. It has been proved that species of *Paramecium* and other protozoans cannot live in waters in which smaller protozoans or bacteria are not present.

When food ciliates are exhausted in the medium, the living ciliate genus *Leucophrys* decreases in size, but the shape remains unchanged (Kidder, etc).

Tetrahymena vorax, another living ciliate, exhibits very interesting relationships between the kind and amount of food and its size and shape (Kidder, etc). Bacteria-feeders are tailed and vary between 50 and 75 microns in length; saprozoic forms, which take nourishment through the body surface by diffusion, are ovoid to fusiform in shape and vary between 30 and 70 microns in length; those living on dead sterile ciliates are fusiform and are 60 to 80 microns long; and carnivores and cannibals are irregularly ovoid in shape and are 100 to 250 microns in length.

Mast observed that individuals of the amoeba *Chilomonas paramecium* grown in sterile glucose-peptone solution were much smaller than those cultured in acetate-ammonium solution. *Amoeba proteus*, when fed exclusively on the protozoan *Colpidium*, became very large and extremely fat.

Gigantism among the protozoans is due to cannibalism, and the largest giants are those which have ingested the largest number of their fellows (Dawson). Giants are common and appear in cultures in which scarcity of food is just beginning to be felt. The animals feed upon bacteria as long as the supply is ample. Cannibal giants show an average length of 164 microns as compared with 104 microns for vigorous well-fed individuals, or 92 microns for the starving animals in a giant culture. The shape of the giant forms is frequently quite different from that of normal individuals in the same culture (Giese and Alden).

A protozoan fauna may become dwarfed because of the absence of its favorite food. The ciliate genus *Colpoda* does not attain normal size in the absence of living food such as bacteria (Kidder and Stuart). Certain bacteria may exert a growth-limiting influence on *Colpoda* because of their toxicity or inferior qualities as a food.

TEMPERATURE. Most Protozoa are able to live only within a small range of temperature variation. Experiments have shown that many protozoans become accustomed to an unusually high temperature if the change is made gradually. The optimum temperature for most protozoans is between 16° and 25° C. In nature most of them die at temperatures between 36° and 40° C., although certain species of flagellates have become gradually acclimatized to 70° C. over a period of years.

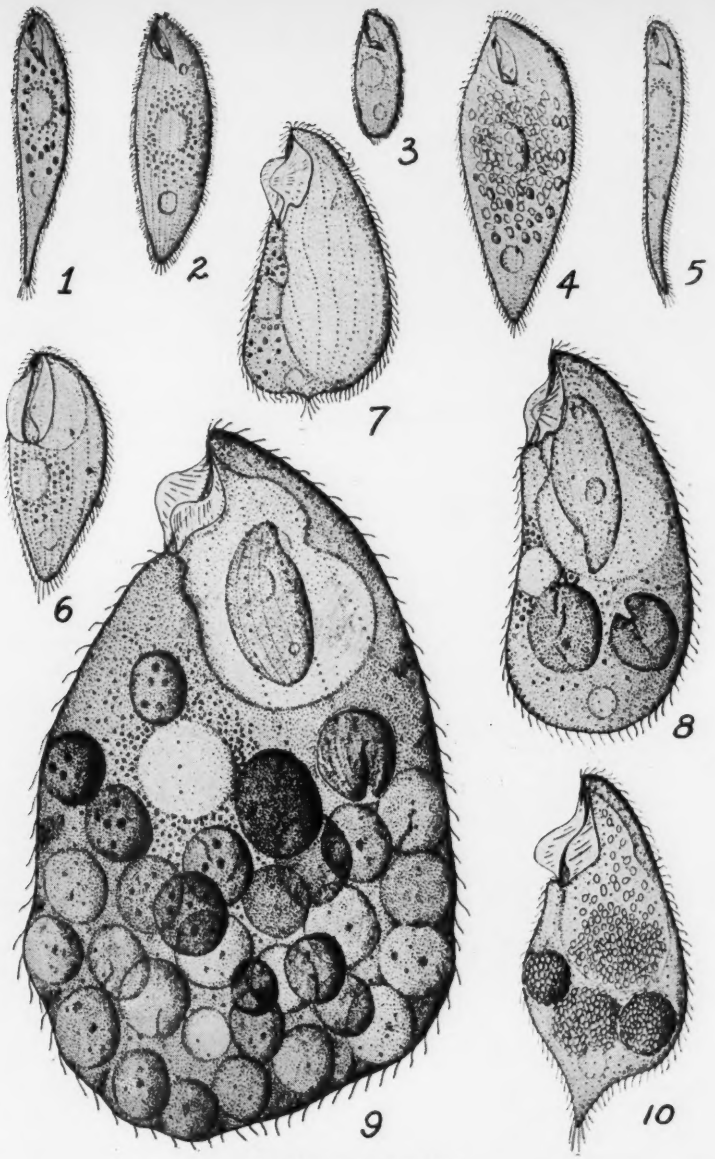
Most protozoans can withstand low temperatures with less detrimental effects than high ones. Amoebae can live at 0° C. for many hours if the medium does not freeze. The *Amoeba* dies, however, as soon as ice forms in its interior.

As a general rule the higher the temperature the greater the metabolic processes of protozoans. Low temperatures decrease the metabolic processes. It is possible, therefore, that some faunas may be dwarfed because of temperatures below normal.

CHEMICAL COMPOSITION AND PHYSICAL CONDITIONS OF THE WATER

The chemical composition and physical conditions of the water in which protozoans live influence their size and distribution. Many protozoan species require water of a certain chemical composition for maximum metabolic activity. Many are also very selective of water with particular physical conditions, such as shallow clear water with a sandy bottom

Morishima reports that *Trochammina globigeriniforme* is found only at the head of Maizurn Bay where the water is low in salinity. He reports an abundance of such genera of foraminifera as *Sigmoilina*, *Rotalia*, and *Eponides* on muddy bot-



EXPLANATION OF PLATE I

Size and shape variation in living *Tetrahymena vorax*, caused exclusively by differences in the kind and amount of food material. ×560. 1, bacteria-feeder; 2, broth-grown saprozoic form during early period of growth; 3, broth-grown saprozoic form during the decline period of the culture; 4, a specimen which has fed on dead *Colpidium;* 5, starved form from a dead *Colpidium* culture; 6–9, progressive size and shape changes of saprozoic form in the presence of living *Colpidium;* 10, a young carnivore which has been removed to a culture with living yeast. (after Kidder, Lilly, and Claff)

toms, whereas *Cibicides* prefers a sandy bottom.

HYDROGEN-ION CONCENTRATION. The hydrogen-ion concentration (pH) of water influences the size of living protozoans, and it is possible that some dwarfed protozoan faunas may have been caused by variations in the hydrogen-ion concentration of water.

In the absence of the proper amount of light it is possible for certain protozoans to become dwarfed because of a deficiency in the food supply.

EXAMPLES OF DWARFED PROTOZOANS. Few references to dwarfed protozoans have been made by paleontologists, although numerous occurrences of dwarfed species and dwarfed faunas are known

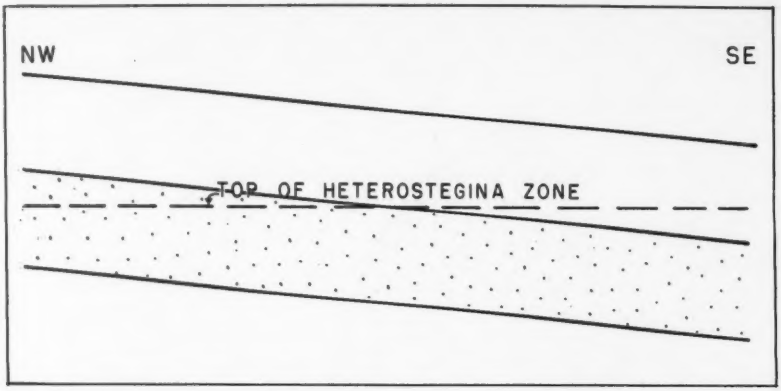


FIG. 1.—Diagrammatic section of a portion of the Anahuac formation of Oligocene age in the Gulf Coast area of Texas, showing progressive marine overlap. Specimens of *Heterostegina texana* Gravell and Hanna, found where the top of the zone is in a sandstone, are large forms of normal size. Specimens found in the overlying shale farther "downdip," however, are very small and apparently dwarfed.

In bacteria-free cultures of *Paramecium bursaria*, it was noted that the length at pH 7.6–8.0 averaged 87 microns whereas at pH 6.0–6.3 the length was about 129 microns, and at pH 4.6 no growth occurred. It appears, therefore, that some Protozoa require a definite pH value for maximum metabolic processes (Loefer).

A low pH value is frequently noted in bottom sediments where a large amount of decomposing organic matter is present.

LIGHT. The amount of light is a factor which influences the distribution of free-living protozoans in water. It is especially important in those protozoans which depend upon chromatophore-possessing organisms as the main source of food.

by current workers in the United States.

One interesting occurrence of a dwarfed species in the Anahuac formation of Oligocene age in the Gulf Coast area of Texas, is that of *Heterostegina texana* Gravell and Hanna. In wells where this species is found in a calcareous sandstone it is large, thick, and apparently of normal size, which is about 4.3 mm. in width. In wells farther "downdip" where this species is found in a shale, specimens are relatively small and thin. The average size is about 1.5 mm. in width. These small specimens were apparently dwarfed because the muddy bottom conditions were unsuited for normal growth. The normal environment for this species was apparently shallow clean water where

sand was being deposited.

Some very interesting occurrences of abnormally small foraminifera of the related genera *Endothyra* and *Plectogyra* have been observed by Zeller in rocks of Mississippian age. In the St. Joe limestone, basal Osagian, in northeastern Oklahoma, all of the specimens of *Plectogyra* appear to be dwarfed. The average size of the specimens in this formation is 0.3 mm. in diameter, whereas the normal size averages 0.9 mm. in diameter in adjacent formations. The St. Joe is a conglomeratic oolitic limestone in which the pebbles and the remainder of the rock are oolitic.

The St. Louis limestone, middle Meramecian, at East St. Louis, Illinois, has an abundance of giant forms of *Endothyra* with an average diameter of 1.5 mm., and also rare dwarfed specimens of the same genus with an average diameter of 0.3 mm. The work of Dawson upon cannibal giants of living protozoans has shown that one would expect to find dwarfed specimens in a fauna which contained giants.

The Salem limestone, basal Meramecian, of Indiana, contains a giant fauna of both *Endothyra* and *Plectogyra* which make up 85 per cent of the rock. Zeller has not yet noted any dwarfed specimens of those genera in this formation. The invertebrate fauna, however, which consists of brachiopods, gastropods etc., is dwarfed.

Garrett has noted foraminifera which are apparently dwarfed in the subsurface Wilcox and basal Claiborne, Eocene age, in Texas. In addition to the small size, the number of specimens is small. He has noted a similar condition in bottom samples taken from some of the brackish stream channels which empty into Galveston Bay.

Cushman has observed the decreased size in several species from the colder waters of the north Pacific Ocean compared with specimens of the same species from tropical waters.

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AUGUST, 1948

ASSEMBLAGES OF DIMINUTIVE BRACHIOPODS AND THEIR PALEOECOLOGICAL SIGNIFICANCE

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ABSTRACT

Assemblages of diminutive brachiopods may result from any one or any combination of the following factors: (1) actual dwarfing due to physiological retardation of growth, (2) accumulations of immature specimens of normally larger species and adults of smaller species due to segregation by moving water, and (3) accumulation of immature specimens because of environmental factors tending to produce subnormal life-span or exceptionally high mortality of the younger shells. Interpretation in any given instance is a matter of determining from the shells themselves, from careful comparison with recognizably normal assemblages of near homotaxial equivalence, and from the physical and chemical nature of the entombing sediments which factor or combination of factors is the more logical. The paleoecological significance of assemblages of diminutive brachiopods as such is thus indirect. They merely bring attention to a situation the interpretation of which depends on a variety of physical, chemical, and biological considerations.

The brachiopod faunas of the "Tully pyrite," the "Clinton hematite," the Glen Park and Salem limestones, and the Windsor series are briefly discussed. The fact emerges that more data are needed on the ecology of recent brachiopods and on assemblages of diminutive fossils and their entombing sediments.

DISCUSSION

Much remains to be learned about the environmental significance of all sorts of faunal aberrancies—including the assemblages of small to minute individuals commonly referred to as "dwarf-faunas." In the ensuing discussion I shall try to summarize briefly the available published information relating to assemblages of diminutive brachiopods and to consider in a similarly brief manner the matter of interpretation. Restrictions of time make it inadvisable to consider fossil assemblages outside of North America, such as those of the Zechstein of Europe.

The most widely publicized assemblages of notably small brachiopods in North America are found in the so-called "Tully pyrite" of late Middle Devonian age, the Middle Silurian Clinton-type iron ores, the lower Mississippian Glen Park limestone, the middle Mississippian Salem limestone, certain limestone beds in the upper Mississippian Windsor beds of Nova Scotia, and in black shales and highly argillaceous limestones of various ages and localities (*e.g.* "Genesee" shale, upper Cayugan limestones). These occurrences were a matter of record by the year 1908, when Hervey W. Shimer published in the *American Naturalist* a brief summary paper titled, "Dwarf-faunas." Little that is really new has been done with the subject since that time, and Shimer's paper stands to date as the summary reference.

Shimer recognized that the assemblages of notably small individuals which we loosely refer to as "dwarf-faunas" included two sorts of things. In one instance the various individual specimens, for various reasons (five suggested by Shimer), might actually be much smaller when full grown than the normal adult sizes for the several species represented; and in the other instance the assemblage might be merely one of normally small species. Building on the same lines one might suggest that a third possible situation would be that where the so-called "dwarf-fauna" was made up

predominately of immature specimens, either because of circumstances limiting as to life-span or because of physical segregation after death. As a more logical arrangement for known and possible assemblages of diminutive brachiopods I suggest (1) actual dwarfing due to physiological retardation of growth, for whatever reason; (2) accumulations of immature specimens of normally larger species and adults of smaller species due to segregation by moving waters; and (3) accumulation of immature specimens because of environmental factors tending to produce subnormal life-span or exceptionally high mortality of the younger shells.

An assemblage of notably small brachiopods might fit any one or any combination of these categories. Interpretation in any given instance involves determining from the shells themselves, and from careful comparison with recognizably normal assemblages of near homotaxial equivalence, which is the more probable. If the assemblage seems actually to be one of physiologically dwarfed shells, analysis of the sedimentary evidence may suggest the dwarfing agent, and areal study may show the direction and degree of emphasis of the dwarfing gradient. Analogy with existing situations is a valuable guide to interpretation but becomes increasingly difficult to apply as we recede from the present moment in time; and when we attempt to consider groups, such as the brachiopods, whose present ecologic relationships have not been studied in detail. In her classic study of the Champlain Sea, Winifred Goldring concluded, from impeccable analysis and comparison with the modern dwarf-faunas of the Baltic Sea and other bodies of brackish water, that variations in the Pleistocene molluscan fauna of the Champlain and St. Lawrence valleys were directly related to headward decrease in salinity of the Pleistocene sea of that region. One can point to no such lustrous example among the known assemblages of undersized brachiopods. In all instances it is here a matter of inferring from the shells themselves and from the physical and chemical nature of the entombing sediments an explanation for the abnormally small size of the shells in question.

The assemblage of minute fossils found in the so-called "Tully pyrite" is a plausible although not certain instance of physiological dwarfing due to adverse bottom-conditions at the time and place of life and burial. At the top of the Hamilton group in western New York, below the typical Tully strata, are widespread but discontinuous lenses of marcasite that do not exceed a foot in thickness. The fauna of these marcasite lenses, described by F. B. Loomis in 1903, consists of 45 to 51 species, of which 15 are brachiopods. Few specimens exceed two millimeters in diameter and the average size is about one-fifteenth that of comparable species in underlying Hamilton strata. Loomis suggested that the dwarfing was related to the presence in solution or suspension of the iron now represented by the marcasite, and he demonstrated that fish and tadpoles kept in iron-saturated water showed dwarfing effects with regard to iron-free control acquaria. If, as Loomis quite logically speculates, the marcasite were the result of precipitation from ferrous carbonate solutions in the presence of hydrogen sulphide, two physiological inhibitors would have been available; and either the hydrogen sulphide or the iron solutions or both might have been responsible for the results seen. Moreover, we may well infer that under the conditions postulated infant mortality would have been high enough to account for the large number of apparently immature specimens in the assemblage. It is to be noted, however, that G. A. Cooper (p. 51) indicates a possibility that the "Tully pyrite" may be a replacement feature.

The hydrogen sulphide, which Loomis calls upon as precipitation agent for the marcaiste lenses of the "Tully pyrite," was explained as a result of decaying organic matter in foul bottom muds. Hydrogen sulphide so produced has long

been widely in vogue to account for the dwarfed condition of the benthonic elements of black shale faunas in general. It is well known that pyrite is a common secondary mineral of dark shales, that modern marine black muds are commonly foul and sulphurous, and that the faunas of modern black muds are apt to be dwarfed and impoverished. Quite apart from the deleterious physiological effects that hydrogen sulphide appears to have, the very presence of impalpable muds in suspension is probably a growth inhibitor. At this point, of course, we meet the seeming contradiction of the very rich faunas of certain ancient clay deposits. But these may have dwelt in adjacent reefs or fringing shelly colonies where they could be washed into lagoonal clays after death, or they may have lived in quiet waters on local areas of firmer bottom. More data are needed on this problem. Shimer (1908) has suggested a floating habitat in a Sargasso sea as an accessory or alternate explanation for the dwarfed elements of black shales, and Ruedemann (p. 33–34) has argued that certain inarticulate brachiopods found in black shales were actually epiplanktonic in habit, living on floating seaweeds. However, no brachiopods are known to live in this manner today.

In his paper on the "Tully pyrite" Loomis also points out that specimens collected by him from fossiliferous hematite in the Middle Silurian Clinton group at Rochester, New York, averaged about one-third the diameter of comparable species from strata above and below the ore bed. This situation he also attributed to the dwarfing effect of iron in solution at the time of life of the brachiopods and other fossils of the Clinton ores. Similar dwarfing effects are reported for the faunas of the Clinton hematites at other localities. Here is an instance where an abstract biologic consideration played a significant part in a problem of economic importance. Are the Clinton hematites primary and more or less continuous or are they a secondary replacement and irregularly distributed at depth? Loomis and other paleontologists insisted that the faunas were dwarfed and that iron in solution or suspension in the Clinton seas was responsible for the dwarfing. Alling (1947) indicates a much lesser degree of dwarfing than Loomis claimed; but Alling, like most of the more recent workers, indicates that iron in solution was probably present at the time of life of the faunas of the Clinton hematites and that it was being precipitated as they accumulated. The faunas of the Clinton hematites nevertheless remain a problem, and the paleontological contribution to the economic problem may be more a matter of accident than perspicacity. The fossils from the hematite beds may well be dwarfed, but they are also water-worn, suggesting the effects of current-sorting.

The undersized brachiopods of the limestone members of the upper Mississippian Windsor strata of Nova Scotia have been attributed to a habitat of shallow turbid water or to the presence of sulphuric acid in solution (Shimer, pp. 484–485; Dawson, pp. 262, 279–280). W. A. Bell p. 64), however, does not regard the Windsor faunas as demonstrable dwarf-faunas in the sense of the individual specimens being undersized adults. He states that there is truly a preponderance of immature individuals at the horizons in question but points out that the occasional truly adult individuals found are not conspicuously undersized. Bell evidently suspects that the true explanation lies in current-sorting and youthful demise.

The fossil assemblages of the Salem limestone of Indiana are made up of dominantly small to minute individuals (Cummings and Beede). The brachiopods and other normally larger shells of the oölitic limestones which characterize the Salem limestone are several times exceeded in size by comparable species from adjacent strata, and the foraminifer *Endothyra* and ostracods are common faunal elements. As in the instance of the Windsor faunas, however, it may be debated whether the faunal elements of

the Salem limestone are truly dwarfed in the sense of being characteristically undersized adults. Cummings and Beede point out that at some localities specimens from the Salem limestone attain approximate normal size. The lenticularity and generally detrital nature of this oölitic rock are matters of general knowledge, and Cummings and Beede have emphasized the fact that it is featured by cross-bedding and that the fossils, in addition to being small, are commonly water-worn. From the published record it would seem permissible to suppose that the so-called "dwarf-fauna" of the Salem limestone might well be the result, in part at least, of segregation and clastic concentration of small fossils by the physical activity of moving waters. If this is true, adult stages should be found in laterally equivalent rocks. It is, nevertheless, a fact that some of the very small brachiopods from the Salem limestone show the beak-features of adult shells, and full explanation may involve more than mere physical segregation.

A generally similar situation to that of Salem limestone is found in the Glen Park limestone of basal Mississippian age. The oölitic limestones of this unit, commonly referred to as the "Hamburg oölite," contain an abundance of mostly tiny fossils. Occasional larger shells are found and some of the small ones seem clearly full-grown. However, the preponderance of the brachiopods that I have seen from this horizon have the beak-features of immature shells. The fossils suggest concentration by physical agency of mostly small shells—some immature, others the adults of small species. Again one may suspect lenticularity of deposits and predict the discovery of adult stages of the immature shells in laterally equivalent rocks. In both instances, of course, the prediction remains to be proved. Detailed lateral tracing and coördinated faunal and lithic analyses are the *sine qua non* of definitive paleoecology.

E. Percival (fig. 1) has plotted interesting size-data for a population-sample of 711 specimens of the Recent terebratuloid brachiopod *Terebratella inconspicua* from Lyttleton Harbor, New Zealand. Four year-classes of growth are indicated by his data, with nearly two-thirds of the population consisting of the relatively tiny specimens of the first year-class and only one-thirty-fourth of the population being of the fourth year-class. Moreover, the largest specimens from Lyttleton Harbor were only two-thirds as large as the larger specimens of the same species from Foveaux Strait at the south of New Zealand. Percival gives no data on environmental differences. Perhaps the waters of Lyttleton Harbor are dirty or slightly brackish, and they are probably warmer than those of Foveaux Strait. In any event very little current segregation would seem necessary to produce at Lyttleton Harbor an assemblage of diminutive brachiopods that might appear dwarfed in comparison with one of equivalent age that lived and was buried under different circumstances. Perhaps mortality at an early stage of growth is unusually high at Lyttelton Harbor. If so the evidence should be found in the beak-features of the young shells.

Now I do not wish to leave the impression that I suppose all concentrations of dominantly small shells to be due either to unfavorable chemical conditions resulting in true physiological dwarfing, as may be the case in the instance of the so-called "Tully pyrite," or to segregation of small individuals by current action. Environmental features that might affect growth rates include not only chemical factors such as concentration of iron compounds, presence of hydrogen sulphide or other gases, and variation in the more normal salts of sea waters, but variation in temperature and changes incident to varying depth as well. According to Shimer the optimum growth rate for an animal is prone to fall off with variation either above or below a normal temperature, and assemblages of diminutive but sexually mature animals

have been experimentally produced under unfavorable conditions of temperature (Shimer, 477).

As a matter of speculation one may also suggest that marked paucity of available calcium carbonate in solution might produce dwarfing effects among the calcareous shelled animals at any locality so affected. One should expect dwarfs so produced to be thin shelled as well as undersized—the effect commonly seen in black shale faunas. Individuals dwarfed for metabolic reasons in the presence of abundant available calcium carbonate might be expected to have thick shells and to show crowded growth-lines and adult beak features. Some of the brachiopods from the Salem limestone are so characterized, but if physiological dwarfing of these specimens occurred, evidence of casual factors is lacking at the sites of deposition. The beak features of the short hinged telotremate brachiopods are especially distinctive of relative stage of growth. Immature shells are apt to show nearly straight beaks and delthyria only slightly modified by incipient deltidial plates. With increasing maturity stronger curvature of the beak and fuller coverage of the delthyrium is attained.

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ENVIRONMENTAL SIGNIFICANCE OF DWARFED CEPHALOPODS

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ABSTRACT

Dwarfed and/or small cephalopods have been recorded from many parts of the geologic column. Data assembled from preliminary studies of the Cretaceous pyritic micromorph faunas of Texas and from an Upper Triassic (Norian) fauna from the Cordillera Central of northern Peru will be given. Both of these faunas contain an abundant cephalopod assemblage, mostly small in size, which are associated with other dwarfed and non-dwarfed invertebrates. Students of cephalopods are handicapped by the relative small amount of environmental data known on recent Nautilus. Some qualitative data on the environmental relationships of fossil cephalopods is known but practically no quantitative data is available. It is suggested that evolution has probably been an important factor in causing the development of some groups of small cephalopods.

Small cephalopods are quite common in many parts of the geological column throughout the world. It appears to be a general practice on the part of cephalopod students to call most small individuals dwarfs with no additional comments. In any discussion of dwarfism and environment one must necessarily draw heavily on observations and ecologic studies of modern invertebrates. Basic environmental data on modern *Nautilus* is very fragmentary and in some cases conflicting. There has been a great deal of speculation on the environment and living habits of fossil cephalopods. One outstanding contribution in this line of study is that by Gayle Scott (1940) on the Texas Cretaceous ammonites. There is, however, the widest latitude of opinion on the living habits of fossil cephalopods amongst students of this group. This state of affairs will exist as long as our knowledge of living *Nautilus* remains so meager. It is my opinion that the primary data on dwarfism and its environmental factors will have to come from the studies of other invertebrate groups. The data assembled from the cephalopods will for the time being need to be secondary.

It has long been believed that maturity in fossil cephalopods is recognized by the closer spacing of the last several septa. Ornamentation and general stage of development are also important criteria but must be used with caution. It is unfortunate that there are numerous species of cephalopods described on the basis of young forms. For our discussion of dwarfed forms it is pertinent to establish the status of maturity of the material on hand. Collection from some 20 Pawpaw formation (Lower Cretaceous) localities in Texas has yielded hundreds of specimens of *Engonoceras*, mostly fragmentary, and only a mere half dozen are complete and mature specimens including the living chamber. The complete specimens show that the species of *Engonoceras* in the Pawpaw are not so small as one is led to believe from the literature. It appears that conditions of fossilization were such as to leave only the inner and stronger volutions intact. The concentration of young forms in localized areas killed off in mass by rapidly changing ecologic conditions is also recognized. In the various monographs on dwarfed Cretaceous ammonites there is little evidence that the authors were too preoccupied in trying to establish the status of maturity of their material. Under these circumstances it is difficult to evaluate some of the data.

For my discussion I will confine my comments to two faunas that present

widely diverse conditions of preservation and environment. The first is a silicified fauna from the Upper Triassic (Norian) limestones in northern Peru and the second will be the Cretaceous "pyrite" faunas of Texas. The Triassic fossils from Peru occur in thick-bedded, dark-gray, bituminous limestones containing much chert. The fossils are silicified and for the most part small in size but very abundant. The residue from the etching of these Norian limestones usually produces a heavy-black, bituminous mud. Other blocks showed a large content of fine silt. The fauna consists of cephalopods, gastropods, pelecypods, brachiopods, bryozoa, sponge spicules, and crinoid stems. The cephalopods belong to eight genera of ammonites and one nautiloid. The most common ammonite genera are *Rhabdoceras*, *Placites*, *Nevadites*, *Anolcites*, *Sageniles*, and *Metasiberites*. By far the most important pelecypod is *Pseudomonotis ochotica*. This fauna has been discussed by Jaworski (1923) who regarded the ammonites as dwarfed. However, in spite of the fact that the ammonites are small, further study is needed to determine whether they are actually dwarfs. *Placites* sp. from Peru is closely allied to *Placites humboldtensis* of the upper Star Peak formation of western Nevada which averages around 27 mm. in diameter. Jaworski had only two specimens for study, one 6.5 mm. and the other 12 mm. in diameter. My collection contains more than a dozen specimens which are the size of those studied by Jaworski, with one exception. A specimen was found showing enough of an outer whorl to indicate that the specimen had attained a diameter of at least 25 mm., thus is similar in size to *Placites humboldtensis*. *Rhabdoceras curvatum* of Peru is closely allied to *Rhabdoceras russelli* of the Norian rocks of California and Nevada and is approximately the same size. Both of these genera are restricted to the Upper Triassic and appear to be merely small ammonites and not dwarfs. From the above discussion on *Placites* it is clear that quantity of material on hand and degree of preservation are important factors to be considered.

Some of the other ammonite genera present quite different problems. The genus *Nevadites* was established by Smith for Anisian ammonites from California, and the species average 50–100 mm. in diameter. The only extra-American occurrence is in Japan where Yabe and Shimizu (1927) record one questionable species from Anisian-Ladinian beds that also reaches approximately 100 mm. in diameter. The Peruvian forms average 10 mm. in diameter. The genus *Anolcites* is mainly an Anisian form occurring also in the western United States and in the Alpine region. The only other occurrence known is from the Norian of Peru. The Anisian species average 90 mm. in diameter and the Norian species 10 mm. There exist no other contemporaneous Norian rocks containing these particular genera or species. It is generally known that one possible evolutionary trend amongst ammonites is a decrease in size. Rather than look to environmental dwarfism as an explanation for the small size, it is suggested that they may represent merely the end forms of an evolutionary lineage and the small size is a product of evolution and not a direct result of the existing environment. Amongst the associated invertebrates which occur with the ammonites, it is important to note that *Pseudomonotis ochotica* is of normal size. The other pelecypods, namely *Phaenodesmia*, *Leda*, and *Anodontophora*, also appear to be of normal size, as do the remaining elements of the fauna.

From the above preliminary observations on the Triassic fauna from Peru the following facts are noted: (1) The environment of life was favorable for the deposition of a great thickness of massive cherty, dark limestones. The site of deposition was probably well out in the geosyncline. (2) The fauna is composed of many diverse elements, of which, only the ammonites appear to be abnormally small. (3) Some of the Peruvian ammonites are the same size as those occurring

in California which are not regarded as dwarfed. (4) Other genera, whereas they are only one-tenth the size of closely related forms, are not known from any other contemporaneous strata.

Thus it is suggested that their size may be due to evolutionary factors rather than direct environmental causes. If they are regarded as dwarfs, the environmental factors causing the dwarfism would appear to act selectively affecting some genera and species and not others.

The second fauna from which data will be given are the pyrite micromorph faunas of the Cretaceous of Texas. The pyrite faunas usually occur in the calcareous clay facies of the Fredericksberg, Washita, and Eagle Ford strata (Adkins, 1918; Böse, 1927). The faunas in general are very diverse containing mollusks, corals, crustaceans, bryozoa, brachiopods, echinoids, and ophiuroids. Ammonites are generally abundant and include more than a dozen genera. Species of *Turrilites, Engonoceras,* and several genera of the heteromorph cephalopods are the most common forms. Similar pyritic micromorph faunas are found in Cretaceous rocks of Europe and Africa.

On the outcrop the pyrite micromorphs are associated with fossils preserved in calcite and apparently not dwarfed. As a general rule only those invertebrates with shells of aragonite are pyritized; there are exceptions to this, however. In the Grayson formation occur abundant *Exogyra arietina,* various pelecypods, echinoids, gastropods, fish remains, and worm tubes all preserved in calcite. It is significant to note that, since the pyrite micromorphs can be seen and collected only on a weathered outcrop, it is not known for certain whether the calcareous and non-dwarfed individuals are actually directly associated with the pyrite micromorphs. The possibility exists that the non-dwarfed individuals occur in separate thin beds interbedded with the pyrite faunas.

The origin of the pyrite and the environmental conditions existing at the time of deposition probably hold the main evidence to explain the dwarfism of the fauna. F. B. Loomis (p. 895, 1903) writes of an experiment in which small fish, tadpoles, and snails were kept in an aquarium saturated with an iron compound, and all the individuals showed dwarfed effects after eight months. Sarasin (p. 207, 1917) records a freshwater lake in New Caledonia whose waters were rich in iron, and the animal life was inhibited and dwarfed. Loomis explained the dwarfed pyrite fauna of the New York Devonian at the horizon of the Tully limestone as due to hydrogen sulfide emitted from decaying organic matter or to the presence of iron or to both. The pyrite would be formed by the reaction between the ferrous carbonate and the hydrogen sulfide giving pyrite, carbon dioxide, and water. This Devonian pyrite fauna contains gastropods, pelecypods, cephalopods, and brachiopods. The brachiopods and pelecypods are the most decidedly and uniformly dwarfed. The gastropods and cephalopods are small but have some large-sized representatives. The differential effect of the dwarfing, Loomis attributed to the different living habits of the various invertebrate groups; the gastropods and cephalopods being more mobile could enter or leave the pyrite environment more easily.

Gayle Scott (1924) explained the dwarfing of some of the Texas Comanche faunas as due to oxygen starvation. He believed that the decaying organic marial in the sea must have extracted considerable amounts of oxygen from the water. In this explanation it is open to question whether any but anerobic organisms would be able to survive an environment that is low in oxygen and with much hydrogen sulfide. Since Comanche pyrite faunas contain great numbers of benthonic species, such as corals, pelecypods, gastropods, starfish, ophiuroids, etc., any concentration of hydrogen sulfide would appear to kill off these forms and prevent any such benthonic life to exist. What sort of a balance between the amount of hydrogen

sulfide present and the ability the various invertebrate groups have to survive and readjust themselves is not known. The actual amount of pyrite in the form of fossil casts and concretions present in some of the Comanche formations is relatively small.

The experiments by Loomis and the field observations by Sarasin have shown that animals living in waters containing sufficient iron are inhibited in their growth. In any explanation of the formation of pyrite which is present as fossil casts and concretions one cannot visualize a great concentration of hydrogen sulfide; this type of environment would surely be lethal to most invertebrates. However, when one considers the relatively small amount of pyrite actually present in some of the Texas Comanche formations, it would appear that the decomposition of the soft parts in the individual invertebrate might produce enough hydrogen sulfide to react with any iron in solution in the sea water to crystallize pyrite in the shell and thus form the pyrite casts. In most specimens the replacement by the pyrite was not complete, and the remainder of each chamber or parts of the interior was filled by calcite.

There are other factors on the environmental significance of the cephalopods not brought out in the discussion of the Peruvian Norian fauna or the Comanche pyrite faunas that need mention. Undoubtedly quantity and quality of food present in any invironment play an important role in determining the ultimate average size of the individuals in a population. This problem is difficult to evaluate in fossil faunas. Salinity is another important factor; it appears that cephalopods cannot endure decreased salinities but apparently can exist in environments in which the salinity is above normal; however, no quantitative data were found. It is not known whether increased salinities could have dwarfing effects on cephalopods. Information on temperature ranges of cephalopods is scanty. It is worth noting that the eggs and embryos of modern cephalopods are intolerant of temperature changes.

In conclusion, it can be seen that cephalopods by themselves as indicators of specialized environments are limited, due to the complete lack of any modern ammonites and an all too meager amount of information on modern Nautilus. Some good qualitative information is known but the much-needed quantitative data are very small. Important in this phase of the study of cephalopods are factors of preservation and the criteria for determining mature individuals.

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FIG. 1, AUGUST, 1948

SIGNIFICANCE OF CRUSTACEANS IN DWARFED FAUNAS

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ABSTRACT

A survey of literature on fossil and living crustacea fails to uncover a single reported case of unquestioned dwarfing.

The molt stages of crustacea introduce a factor that is not ordinarily involved in the study of other invertebrates. Ostracodes pass through 7–9 molt stages. It is conceivable that a group of molts could be misinterpreted as "dwarfing."

An investigation concerning dwarfing in trilobites failed to uncover any evidence which would indicate the existence of such a fauna.

The crustaceans are normal in dwarfed faunas because they were free swimming forms and lived in that portion of the water which had a normal pH. Whereas, the dwarfed forms were bottom dwellers that lived in an environment where the pH was low and the H_2S high.

In considering the problem of dwarfing in crustacean faunas the discussion can be limited to the ostracodes and trilobites. These are the only two groups that occur abundantly as fossils. Unfortunately, no experimental data on dwarfing in modern crustaceans is available. This report concerns a study of fossil crustaceans and their relationship to normal and dwarfed faunas with special attention to the environmental conditions.

DWARFING IN OSTRACODES

Ostracodes make their home under a variety of environmental conditions. Different genera and species have distributed themselves over the earth in saline water of the open sea, in brackish water of bay and lagoon, in fresh water of large lakes and ponds, in muddy rivers and clear brooks, in swamps and drainage ditches, in water collected in the hollow of a log, and from the Arctic to the Tropics. They are among the best animals known to the writer as indices of past and present environments.

Small ostracodes have been reported from many zones, but they are not the result of dwarfing. Their smallness is due to the fact that ostracodes pass through several molt stages. Depending upon the species, an ostracode may pass through seven to nine molt stages. These molt stages vary from approximately one-tenth of a millimeter to an adult form which has a size of approximately 1 mm. It is conceivable that the occurrence of numerous small ostracodes could all represent molt stages of some adult form. It should be borne in mind that a much larger number of ostracodes lived as molts than ever reached the adult stage.

The only instances of ostracodes known to occur with other fossils considered to be dwarfed are the cases sighted by Loomis, 1903, from the Tully limestone in northern New York, by Cummings, Beede, and Smith, 1906, from the Salem of Indiana, by Spivey, 1939, from the Maquoketa of Iowa, and by Croneis and Grubbs, 1939, from Silurian sea balls in Illinois. Loomis reports the occurrence of two genera, *Beyrichia* and *Entomis*, associated with 46 species of other fossils. However, both of the ostracode genera from the Tully can be considered perfectly normal sized representatives of their kind. The average ostracode is .60 mm. to 1.00 mm. in length. The Tully specimens of *Beyrichia* are .60 mm. in length and those of *Entomis* are 1.12 mm. in length. Obviously, these are normal to large members of the genera represented.

Spivey, 1939, has described seven ostracode species from the Depauperate

Zone of the Maquoketa. He lists *Primitiella carli, Primitia gibbera, Primitia bellevensis, Milleratia cincinnatiensis, Bollia ruthae, Zygobolboides grafensis,* and *Maccrocypris kayi.* These range in length from .40 mm. to .85 mm., averaging .71 mm. They are typical of normal sized adult ostracodes. Two of the seven species have been reported from other areas, but they conform in size.

The fauna of the Spergen-Salem has been reported to be dwarfed. I have in my collection most of the type specimens of ostracodes known from the Salem limestone. It is a varied fauna represented by 17 genera and 46 species. The individuals present are at least normal in size and perhaps are slightly larger than average. They were a successful race during Spergen times and all forms that did not meet with some unfortunate accident attained the full ostracodal maturation of about 1.00 mm. in length.

If the species associated with the average ostracodes are truly dwarfed forms it is obvious that the conditions which resulted in dwarfing had no influence on the ostracodes. In view of the varied habitat in which modern ostracodes live, ranging through the most diverse kinds of environments and the lack of any evidence whatsoever pertaining to the existence of dwarfed faunas, fossil or recent, we are forced to the conclusion that dwarfing is not known to exist in the ostracoda.

DWARFING IN TRILOBITES

Loomis, 1903, reports the occurrence of *Cryphaeus boothi* and a fragment of *Dalmanites* from the Tully of New York. He states that both of these are normal specimens insofar as size is concerned and suggests that they appear to be individuals that wandered into a pyrite area. Whether that is a fact or not cannot be said, but it is true that there is no evidence to support the concept of dwarfing in Tully trilobites.

Ladd, 1928, states that trilobites occur in the Depauperate Zone of Iowa, however he does not give us any information as to whether or not the trilobites are actually dwarfed, or whether they are normal forms within a depauperate fauna.

Christina Lochman Balk of the University of Chicago has written to me concerning the question of dwarfed trilobites. I quote from her letter of March 2, 1948:

"In all the faunas in the Upper Cambrian I have worked with and in the Lower and Middle Cambrian material I have examined the general impression I have obtained has been one of a normal fauna. However, when one considers the nature of our fossils—I believe that a good 75% at least must represent molts—it is extremely difficult to evaluate the meaning of size in the specimens. In the Upper Cambrian faunas, the cranidia and pygidia have acquired specific features by the time they reach 2–3 mm. in length. The great majority of trilobite fossil specimens generally run about 5–10 mm. in length of cranidium and pygidium and so give the over all picture of the average trilobite being about several inches in length. However, in a very large collection I have often found much larger fragments of the cranidia and pygidia of these average sized individuals so that I believe some of the apparent generally small size of trilobites is due to artificial means of preservation. Anyhow, for the Cambrian I can say, that with what we do know we certainly cannot point out a definite case of dwarfing in trilobites—but our present knowledge is so limited that, on the basis of that situation—we cannot positively declare that it didn't or couldn't even occur."

Mississippian, Pennsylvanian and Permian trilobites are characterized by small size, but no one has ever suggested that size in late Paleozoic trilobites is due to dwarfing. They occur through a great stratigraphic range as small representatives of a declining race. Surely, smallness in this sense cannot be considered dwarfing.

It is important to note that Mrs. Balk has called to our attention that perhaps 75 per cent of fossil trilobites are represented by molts. In other words, the mere occurrence of a large number of small

trilobites is not cause for concluding that dwarfing is represented.

Though the trilobite fauna of the Ordovician Depauperate Zone of Iowa needs further study, we can say that there exists today no definite evidence of dwarfing in trilobites.

EVIDENCE BEARING ON DWARFING OF MODERN CRUSTACEA

I have discussed the problem of dwarfin in modern faunas with Dr. V. E. Shelford, ecologist, and Drs. H. J. Van Cleave, L. Ingle, and M. R. Matteson, invertebrate zoologists, all of the University of Illinois. None of these men know of any cases of dwarfing in modern crustacea.

Ingle pointed out that crayfishes collected from ponds and lakes formed in areas of strip-mining for coal are perfectly normal in size. Some crayfishes collected from such waters are red in color due to a coating of iron oxide on the exterior of the carapace, others may be coated green due to the high concentration of copper sulfate. In both cases the high concentration of mineral matter did not affect the size of the crustacean. Normal ostracodes have also been reported from similar waters of high concentration of iron or copper. In other words, we have evidence to indicate that the size of a crustacean is not controlled by a high concentration of iron or copper in the habitat. Crayfish and ostracodes have been reported from still water to swiftly moving water, ranging in temperature from cold to warm, from fresh to salty; yet none of these factors have influenced size.

According to Ortman's law, the size and shape of a pelecyopod shell varies according to the position that it occupies in a stream, smaller sizes developing toward head waters. This law cannot be applied to crustaceans.

On first thought it might appear that the lack of dwarfing in crustaceans would be of no aid in interpreting the causes of dwarfing in other forms. However, the crustaceans as active, mobile animals, live under different conditions than the slow moving bottom dwelling forms, so they afford us an opportunity to contrast conditions within a given body of water. Let us now examine these contrasting conditions.

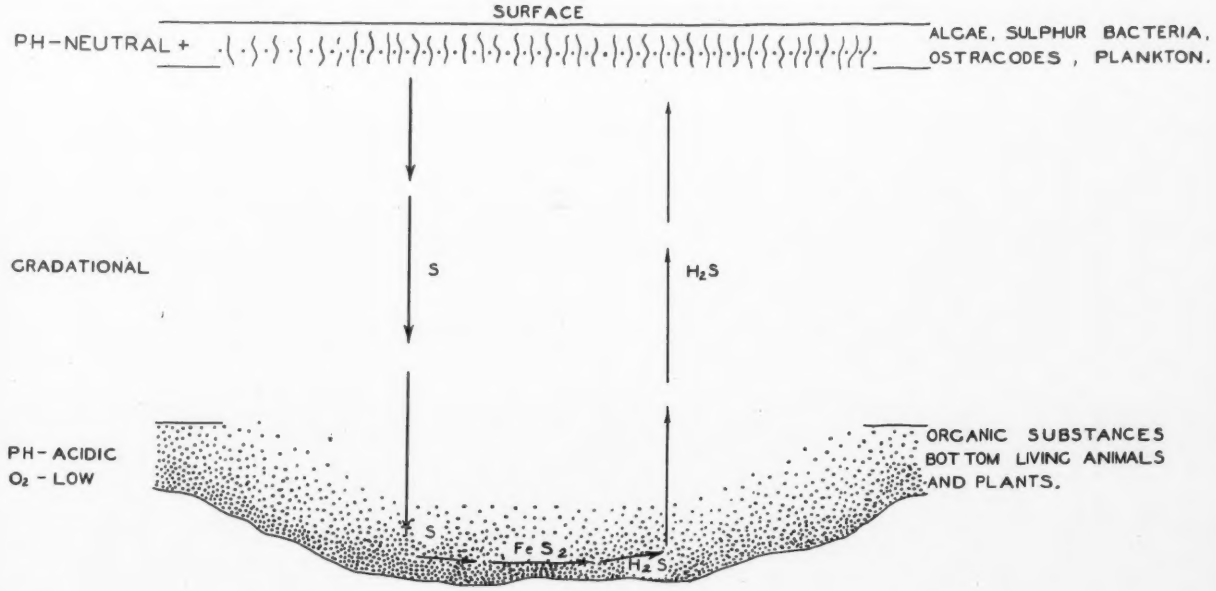
CAUSES OF DWARFING

It is a well-known fact that the pH content of water is a factor which controls the presence or absence of life. If the pH condition changes toward the acidic side the number as well as the size of organisms may be reduced. If the toxic condition is increased the environment may become inimical to all forms of life. Different animals can withstand different degrees of toxicity.

Humphrey and Macy, 1930, have made observations on the factors which control the size of snails in tidal pools. They studied *Littorina scutulata* and *L. sitchana* in tide pools of the San Juan Islands near Friday Harbor, Washington. They studied only those pools which were not connected to the sea and made observations on temperature, salinity, depth, slope and nature of the floor, biotic assemblage, and hydrogen-ion concentration. They show that the size of *Littorina* increases with an increase of salinity, oxygen content, and temperature; and decreases with an increase in acidity. They also concluded that amount of exposure, wave action, and slope have no bearing on size.

Powers, 1920, has made an extensive study of the hydrogen-ion concentration in sea water. The lowest pH found in the water of the Puget Sound area occurs in zones of poor circulation where there is an accumulation of decaying substances.

In general, there is a decline in the pH with an increase of H_2S and a corresponding decrease in the oxygen content. Many workers have reported a decrease in pH with an increase in depth. They have shown the importance of the hydrogen-ion concentration in general physiological processes. Numerous investigators have pointed out the importance of this factor as it applies to the early stages of development in marine animals. Every spe-



PROBABLE ENVIRONMENT
FAVORABLE TO DWARFING

cies seems to have a range of hydrogen-ion concentration within which they can live and reach normal maturity. McClendon, 1916, reports that marine animals tested by him could not live outside of the pH limits of 6–8.25, and that the oxygen consumption of marine invertebrates varies with the pH.

One of the most significant observations pertaining to size has been made by Matteson* on clams found in lakes in Michigan.

"There are several lake environments in which I have collected mussels where the substratum is composed chiefly of decomposing organic matter. Here one will find mussels, perhaps not so plentiful as in more favorable conditions, but in sufficient numbers as to indicate a permanent population. Food is quite plentiful as the plant material when suspended may, along with plankton, be utilized by the mussels. However, all mussels present are definitely dwarfed, especially members of the genus *Lampsilis*. I believe that the toxic gases liberated by decomposition are the dwarfing factors.

"Each fall during the years of 1943 to 1946, I placed several hundred *Elliptio complanatus* in a large concrete tank of water which remained unchanged until spring. These mussels were used for various anatomical studies connected with the life cycle of this species. The valves were coated with algae, lime and varying amounts of organic material imbedded in clay from the substratum from which they were removed. Occasionally a clam died unnoticed. The gases of decomposition became concentrated. This fact was evident by odors escaping from the water. The mussels became lethargic but did not die. The most interesting observation made was that, after a few months' exposure to these conditions, the mussels' digestive tract presented a strikingly new appearance upon dissection. In cross-section, the cut ends of the digestive tubes appeared as blue-black spots. Microscopic examination of the living tissue revealed that the epithelium lining the digestive tract was stained blue-black by the material taken in while eating. The contents of the digestive tract is highly liquid and various decomposing materials or products of decomposition were present. When clams were taken from the tank and placed in clean water for a few days dissection disclosed that the stained appearance of the epithelium had disappeared.

"I feel that the absorbing ability of the epithelium becomes restricted by the above condition. Therefore, dwarfing is the natural result."

* Letter, March, 1948.

Shelford* states that after many years of marine studies he

"came to regard the amount of H_2S as the best index of the suitability of sea water for a series of animals ranging from herring to stagnant bottom species.

He has shown that 35 parts per million of H_2SO_4 is adequate to kill a 2.25-gram herring.

Harukawa, 1922, has investigated the toxicity of colloidal sulphur and has found it to be more highly toxic than H_2S. Loomis has suggested that the Tully forms, being related to a pyrite zone, were dwarfed because the sea water in which the animals lived was polluted with iron in solution and decaying vegetation. He suggested that the ferrous carbonate was precipitated by sulphuretted hydrogen to form pyrite. $FeOCO_2 + H_2S = FeS + CO_2 + H_2O$. He conceived of this environment as being unfavorable to animal life and that the dwarfed forms were a result of mutations brought about by the presence of the iron carbonate.

The presence of iron carbonate alone is hardly adequate to cause dwarfing; at least it has had no influence upon crustaceans found in modern ponds with a high concentration of iron. It seems more likely that the pH content of the water would be the deciding factor in controlling size. The pH content may be controlled by the amount of excreta formed by the animals. A large concentration of organisms in an enclosed basin such as the shallow brackish-water basins on a delta where the water is not replenished by a new supply, and where neither new

* Letter, March, 1948.

forms could invade nor the old escape would be a place where an excessive amount of excretal material might accumulate. This, plus other decaying organic material, would develop a toxic condition and result in stunting the growth of animals. Some forms are more susceptible to slight changes to the pH content than others. It so happens that crustaceans are known to be among the least susceptible and can survive without any changes in size or form when the pH content varies as much as 6 to 8.

Smith, 1906, suggested that dwarfing of the Salem fauna may have been due to overpopulation, limited food supply, to the smallness of the body of water, and to a depletion of oxygen.

Overpopulation cannot be subscribed to because there would always be those large forms that would feed on the small. Furthermore, over a long period of time the law of biotic potential would be effective. This law may be expressed as BP = RP/ER; BP is the biotic potential or population, RP represents the reproductive potential, and ER the environmental resistance. The population of a given environment will remain at one or unity. Anything that upsets the balance, i.e., an increase in number of one species, will be compensated for by a decrease in other forms. It would appear impossible to have an entire fauna dwarfed by overpopulation alone.

Dwarfed fossil species have been referred to by some writers as mutants. It is not uncommon for dwarfs to develop as mutants in vertebrates or invertebrates, but it is extremely unlikely that an entire dwarfed fauna composed of as many as 40–50 species representing several phyla could be a result of mutation.

DISCUSSION

This paper has cited evidence which indicates that crustaceans are not known to occur as dwarfs within dwarfed faunas. Evidence has also been presented which indicates that the presence of iron in solution is not an important factor in dwarfing, but on the other hand, the pH content of the water, in part controlled by the amount of sulphur present, is probably the deciding factor. The amount of fecal material and the quantity of decaying plant substance are important in the development of H_2S and a rise in acidity. A pH content of approximately 6.5 will result in retarded activity, a decline in food gathering and food assimilation, and thus result in dwarfing. This condition is most likely to occur on the floor of tidal lakes, bays, lagoons or land-locked bodies of water where circulation is poor. Benthonic animals such as brachiopods, pelecyopods, and gastropods are more likely to suffer dwarfing than free swimming species such as most of the crustaceans.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 18, NO. 2, PP. 71–73
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THE USE OF PEELS IN CARBONATE PETROLOGY

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ABSTRACT

Transparent peels provide a useful technique for the study of texture and composition of carbonate rocks. Directions for preparation are given. Advantages of peels over thin sections are discussed with emphasis on the ease of preparation of peels.

INTRODUCTION

The preparation of transparent peels is a standard technique in paleontology, but their use in sedimentary petrology is not widely appreciated. Appel (1933) called attention to the use of such films for the study of textures. He found the method valuable for the study of opaque ores such as the Clinton oolite. Peels may be taken from many kinds of rocks but an etched surface of limestone or dolomite gives the best results. As carbonate petrology is in need of new techniques the usefulness of transparent peels should be investigated by all workers in that field.

This paper was written under the supervision of Dr. John Rodgers of Yale University. Professor Carl O. Dunbar and Dr. Eleanora Bliss Knopf kindly read the manuscript and made useful suggestions.

TECHNIQUE

This outline of the procedure for making a peel will also serve to explain what the term "peel" means. The procedure outlined below is not entirely original; other publications describing it are listed in the bibliography.

1. Cut a plane surface of any desired size and at any desired orientation on the rock specimen and grind it smooth. This surface need not be highly polished but must be thoroughly smoothed so that a uniform surface will be exposed to the etching that is to follow.

2. Etch the smoothed surface by immersing it in 5 per cent HCl. The length of time required for etching will vary with the amount of lime in the rock; about one minute is usually sufficient.

3. After thoroughly drying the specimen, flow a layer of the following solution over the etched surface.

Parlodion	28 grams
butyl acetate (comm)	250 cc.
amyl alcohol	10 cc.
castor oil	3 cc.
ether	3 cc.

This formula, perfected by Darrah (1936), gives tough, transparent peels that never stick to the specimen. A glass rod makes a suitable applicator but the solution must be flowed on as the slightest amount of stirring will introduce bubbles. The solution will shrink considerably in drying but a layer as thick as surface tension will hold in place and dry to a satisfactory thickness.

4. Allow to dry for approximately 24 hours, then loosen the film around the edges with a pen knife and carefully peel it off the rock. There will be no danger of the peel sticking to the rock but it may tear if hastily stripped off. If portions of the rock are soft and fine-grained some of the actual rock may become incorporated in the peel, but in most cases the peel will be an accurate, detailed impression or mold of the etched surface.

APPLICATION TO STUDY OF CARBONATE ROCKS

The peel method produces the best results when applied to the carbonate rocks, especially limestones, because they may be etched to the kind of surface that is most satisfactorily recorded on a peel. There are several advantages to the use of peels rather than thin sections. Most important, they require but a fraction of the time and skill necessary for preparation. The grinding of the smooth surface represents only the preliminary step to making a thin section and the time consumed in making the peel itself is almost negligible. This saving of time is conducive to more detailed study of vertical and horizontal changes in lithology and fossil content of a formation by permitting more frequent sampling. Nearly every geological laboratory has suitable equipment to make peels 6″×2″ in size. Two hundred peels of that size would provide complete vertical coverage of a formation 100 feet thick, providing that conditions permitted sampling every 6 inches. One unskilled technician could prepare that many peels in a few days and by cementing them end to end he would have a complete vertical log of the formation, the equivalent of a thin section 100 feet long by 2 inches wide.

Direct examination of a polished or etched surface without the additional step of making a peel will undoubtedly be satisfactory for some purposes but the use of transmitted light reveals much detail that otherwise would be missed. Peels offer the additional advantages of being much easier to photograph and taking up less space in storage.

Good photographs of peels may be made with a remarkably simple technique. If a peel is placed between two glass plates and projected on a screen in the same manner as an ordinary slide an enlarged and sharp image is produced. Set the camera for a time exposure and take a picture of the screen. Printing on contrasty paper is recommended.

Peels provide an excellent technique for studying the texture of limestones. Size, shape, orientation, and stratification of the component particles of the most fine grained limestones are clearly visible. Peels examined under magnification of 85× showed just as much detail as thin sections at the same magnification. In fact, many of them showed more because of the difficulty of grinding limestone thin without encountering cleavage and comminution of the calcite. In addition, the differential effect of the etching brings out details and patterns in the arrangement of the particles that are not visible in thin sections.

Peels cannot replace thin sections for the study of mineral composition of rocks. They cannot, of course, be studied with the techniques of optical mineralogy, nor can they record differences in color or opacity. However, crystal outlines, cleavage lines, patterns and shapes of the etching marks which pit the surface of many mineral fragments, and differential effect of the etching aid in mineral identification. Calcite is easy to recognize because the etching produces a uniform, frosted appearance on the peel and the cleavage lines usually show clearly. Quartz, on the other hand, does not etch and shows up as a smooth, transparent spot on the peel. A few sample comparisons of peels and thin sections from the same rock will aid in learning how to interpret the peels.

Although peels have been used for many purposes by paleontologists there are still unexploited possibilities in their application to the micropaleontology of limestones. Not only may they be used for the identification and study of the fauna but also for determining what animals have contributed to the formation of the limestone and in what proportions. Although the peels will record the most minute and delicate structures of calcareous fossils it must be borne in mind that if the fossils are silicified only the outlines will show.

CONCLUSIONS

Peels offer the following advantages

over thin sections for the study of carbonate rocks:

1. The fact that they can be made much more quickly and cheaply facilitates a more complete examination of the rock.

2. They show details of structure (due to etching) not noticeable in thin sections.

3. They generally show sharper detail. Because of the softness of limestone only a highly experienced technician can grind slides sufficiently thin to bring out details that are sharply delineated on peels.

On the other hand peels do not show color or degree of opacity and cannot be examined with the techniques of optical mineralogy.

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FIGS. 1–2, AUGUST, 1948

SEDIMENTS FROM PRE-CAMBRIAN ROCKS OF SOUTHERN SANGRE DE CRISTO MOUNTAINS, NEW MEXICO

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ABSTRACT

Pre-Cambrian rocks in the southern Sangre de Cristo Mountains consist chiefly of granites, gneisses, and schists. Detritals released by weathering of these source rocks were studied for mineral content and general properties as sediments. Most of the minerals contain inclusions and have physical and optical properties that permit determination of source rocks.

INTRODUCTION

Exposures of pre-Cambrian rocks occupy an area of about 960 square miles along the summit areas of the Truchas and Rincon Ranges, a bifurcation of the southern Sangre de Cristo Mountains in north-central New Mexico (figs. 1 and 2). This region has been the center of repeated orogenic movements which began in late Magdalena time (Pennsylvanian) and culminated in late Mesozoic time.

The pre-Cambrian rocks consist chiefly of pink and gray granites, gneisses and schists. The granites are probably the most recent of the crystalline rocks, and occupy the core of the major uplifts, the Rincon Range to the east and the Truchas Range to the west. The texture of the granites is unoriented granular and the grains range from fine to coarse. The mineral constituents of the granites include feldspars, chiefly orthoclase and microcline, quartz, hornblende, muscovite, biotite, magnetite, tourmaline, garnet, zircon, rutile and titanite.

FIG. 1.—Map showing the general location of the southern Sangre de Cristo Mountains.

Most of the gneisses have the composition of granite and occur as dikes that intrude the schists. The mineral grains have a linear arrangement and range from fine to very coarse. The gneisses are distinguished from the granites by the arrangement and size of the mineral grains.

Some schists are probably of sedimentary origin as they are associated with layers of crystalline limestone and quartzite. Schistose rocks, chiefly hornblende and mica, outcrop at the margins of the pre-Cambrian exposures. The hornblende schists are coarsely foliated and the mineral grains are arranged in alternating light and dark bands. Dark grains constitute about 80 per cent of the rock and the minerals in order of abundance are hornblende, biotite, magnetite and epidote. The light colored minerals consist largely of quartz, feldspar, zircon and titanite.

The mica schists are finely foliated and the long axes of the mica flakes parallel the direction of schistosity. The mica occurs as foliated aggregates and some of the lamallae are bent and broken. The important minerals are muscovite, biotite, quartz, epidote, zircon and kyanite.

Rock specimens and weathered products therefrom released by weathering of the parent rock, were collected at four localities: on Federal highway 85 south of the city of Santa Fe; in the Pecos Valley north of the city of Pecos; in Gallinas Canyon; and near the town of Mora. The detritals were studied carefully for such characteristics as type of inclusions and other physical and optical properties which might serve to identify the source rocks.

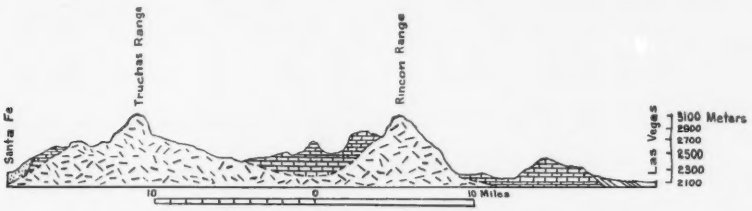

FIG. 2.—Generalized cross section showing exposures of pre-Cambrian rocks. From geologic map of New Mexico.

The writers wish to acknowledge the assistance that was rendered by the Research Division of Texas Technological College.

CHARACTERISTICS OF MINERALS

A study of the minerals from pre-Cambrian rocks in southern Sangre de Cristo Mountain provenance involved two objectives. The first was to determine the properties of the minerals that were contributed by pre-Cambrian rocks at the present time. The second was to summarize the characteristics of minerals, especially those with more than one possible source of derivation, that might serve to identify the parent rocks.

Quartz—Two varieties of quartz, clear and milky, are abundant. The clear quartz was derived chiefly from granites and occurs as angular to partly rounded particles and a few euhedral grains. Milky quartz, an important constituent of the schistose rocks, is found as platy, elongated particles having many of the properties of chert. Five types of inclusions are recognized: transparent and dust-like microlites, well developed crystals of zircon and tourmaline, fluid and gas cavities, irregular opaque minerals, and acicular crystals of rutile and kyanite.

The quartz grains from pre-Cambrian rocks have three possible sources of derivation which are as follows: 1. Granites—This type of quartz includes most of the clear fragments and euhedral grains. Inclusions are limited to transparent microlites, dust-like particles, magnetite grains and fluid and gas cavities. 2. Gneisses—The grains are characterized by weakly developed strain shadows and numerous inclusions of zircon and tourmaline. 3. Schists—Schistose quartz is distinguished by elongated platy grains, well defined crenulated borders, undulose extinction, and acicular inclusions of rutile.

Hornblende and actinolite—Two types of hornblende, dark green and light green, comprise about 75 per cent of the heavy minerals and occur as tabular to elongated particles. Dark green hornblende, with index of refraction 1.646 to 1.653, is moderately pleochroic, whereas, the light green variety, with a slightly higher index of refraction 1.65 to 1.663, is strongly pleochroic. Inclusions of mag-

netite, titanite, zircon, rutile and biotite are common.

A fibrous type of amphibole, probably actinolite, is derived primarily from metamorphic rocks. It occurs as yellowish-green, weakly pleochroic, slender prisms containing a few inclusions of iron oxide.

Hornblende from granites is found as irregular particles and the average ratio of the long axis to the short (using 25 grains) is 10 to 7.6. Inclusions are small and consist of slightly rounded crystals of zircon and irregular grains of magnetite. The inclusions have no definite arrangement and some extend across cleavage planes. Grains from gneisses consist of elongated particles with frayed ends. The long axes of most of the magnetite and zircon inclusions parallel the cleavage planes. Particles from schistose rocks are deeply frayed, and the average ratio of the long axis to the short is about 10 to 4. Acicular inclusions of rutile and stringers of small magnetite grains parallel the long axis of the grains.

Micas—Two members of the mica group, biotite and muscovite, are constituents of the pre-Cambrian rocks. Biotite is represented by the brown and green varieties and the specific gravity of some of the grains is greater than bromoform. The mineral occurs chiefly as cleavage flakes with irregular, often serrated margins. Lamellae in some of the flakes are bent and broken. Bleaching was observed in about 40 per cent of the grains: some are pale yellow, almost transparent; others are mottled; and a few contain light and dark bands. Biotite alters to iron oxide and a yellowish-green mineral having many of the properties of epidote. Inclusions of slightly rounded grains of zircon, usually with halos, elongated crystals of rutile, and iron oxide are common.

Biotite grains from granites occur as short irregular cleavage flakes. Partly rounded crystals of zircon and irregular grains of magnetite are enclosed in the brown variety. Grains from gneisses, except for the elongation of the flakes and deep marginal crenulations, are similar to those from granites. Biotite fragments from schistose rocks are elongated and the ratio of the long axes to the short is about 6 to 2. Lamellae in many of the grains are bent and broken. Many of the particles contain slender crystals of rutile in addition to inclusions of zircon and magnetite.

Most of the muscovite is derived from the coarse grained granites and mica schists. It occurs as colorless to pale yellow unaltered grains with the characteristic bluish gray interference tint. Tapering habit and herring-bone structure is revealed in the large fragments, especially those from coarse grained granites. Undulose extinction is a notable feature in many of the graines from schistose rocks. Zircon and iron oxide inclusions are conspicuous; the former by the abundance of crystals and well rounded grains, the latter by the range in color from bright red circular masses to iron black irregular grains. Less common are rounded grains of quartz and flakes of biotite.

Fragments of muscovite from granites are elongated and many reveal the tapering habit and herring-bone structure. Most of the grains are abundantly supplied with inclusions, particularly opaque minerals, probably magnetite, and crystals of zircon. Grains from schistose rocks consist of partly rounded cleavage flakes and many have undulose extinction. Well rounded grains of zircon and quartz are frequently enclosed in the fragments.

Magnetite—Magnetite occurs as angular fragments, rounded to sub-rounded grains, octahedrons, and inclusions in hornblende, biotite, and quartz. The mineral in incident light is dull black to steel gray and many grains appear to be aggregates of minute crystals. Some of the magnetite, as shown in thin sections, is probably an alteration product from hornblende. The grains are dull black, contain inclusions of hornblende, quartz and chloritic matter, and thread-like projections of magnetite extend into the hornblende. About 20 per cent of the grains have undergone alteration ranging

from a thin surface coating to almost complete replacement by hematite.

Grains of magnetite, though constituents of both granites and schists, generally do not reveal criteria that definitely distinguish the parent rock. However, in the Sangre de Cristo provenance there are a few forms of the mineral that do. The dull, lamellar, rounded to subrounded grains with a slightly reduced magnetic attraction are derived from schistose rocks. Strongly magnetic, angular fragments that contain hackly fracture and minute facets are constituents of granite.

Ilmenite—Ilmenite is a constituent of the granite and the granite gneiss. It is associated with magnetite and intergrowths were noted in a few of the thin sections. The mineral is moderately magnetic and occurs in iron black, angular particles with crimson, sub-metallic luster. A few grains were partly altered to leucoxene. The mineral is of little use in determination of source rocks.

Epidote—Detrital epidote occurs as angular to partly rounded grains, platy particles, and prisms with striae parallel to the long axis. The mineral is colorless to shades of green, weakly pleochroic, and a characteristic feature is the brilliant green-purple-red interference tint. Most of the platy grains reveal the one bar interference figure.

Epidote from the schistose rocks is associated with calcite and consists of nonpleochroic, platy particles with crenulations; partly rounded, light yellowish-green grains; and dark green prisms. Epidote from the granites is less common and the particles are unaltered and nearly colorless. According to Johannsen, epidote is a secondary constituent of granite.

Kyanite—Kyanite in the southern Sangre de Cristo Mountains is limited to the mica schists. It consists of colorless to pale blue prismatic particles that have irregular terminations, prominent re-entrants, and cleavage parting parallel to the prism margin. Some of the grains disclose oblique twinning with the parting about 85 degrees to the length of the fragments. Inclusions are limited to a few transparent minerals and carbonaceous matter.

Tourmaline—Three types of tourmaline, similar to those described by Krynine, are derived from the pre-Cambrian rocks. Most numerous are the green and brown grains from granite. These consist of elongated, irregularly terminated particles that contain microlitic, cavity and transparent crystal inclusions. Less common are the large dark brown to blue, irregular particles from pegmatites. Inclusions are limited to large cavities. Tourmaline from pegmatized metamorphic rocks consist of well developed brown and colorless prisms with pyramidal terminations. Inclusions are rarely encountered.

Zircon—About five per cent of the heavy minerals are zircon. The mineral is in the form of prisms with partly rounded pyramidal terminations, euhedral fragments, and rounded grains. Zircon is represented by three varieties which in order of abundance are transparent, mauve and brown. Fractures in some of the grains are at right angles to the long axis, in others they radiate outward from the center. Zoning is well developed in a few crystals. Four types of inclusions are present: dust like particles, occasionally as chains; elongated, tear shaped and circular cavities; crystals of zircon, rutile and quartz; and opaque grains, probably magnetite.

Zircon from granite consists of crystals and euhedral grains that contain dust-like, circular cavities, small crystals of zircon, and magnetite inclusions. Grains from schistose rocks are rounded, rarely with terminations, and many are foliated. Some of the grains contain an elongated, almost white core which is a center for numerous radiating cracks. Inclusions of elongated cavities and slender crystals of rutile parallel the long axis of the grains.

Garnet—The almandite garnet is a constituent of most of the schists and the mica bearing granites. It consists of light pink, almost transparent, to red angular particles with deep re-entrants. Crystals

are rare. The surfaces of some of the grains contain small, circular solution pits which probably indicate an early stage of weathering. Spotting and rectangular surface markings characterize some of the grains. Three types of inclusion were noted: transparent minerals with index of refraction higher than garnet; partly rounded grains of rutile and quartz; and a few spherical grains of iron oxide.

Garnet from the granites consists of elongated particles that contain small magnetite and transparent mineral inclusions. Grains from schistose rocks are usually short and many are characterized by strain shadows and rectangular surface markings. Large, irregular isotropic inclusions give a drusy appearance to a few of the grains.

Rutile—Rutile occurs as amber to reddish-brown partly rounded grains, prismatic fragments with irregular terminations, and inclusions. Twinning is indicated by striae running oblique to the prism edge. The mineral is weakly pleochroic and because of the strong birefringence the color does not change under crossed nicols. Inclusions consist of a few cavities, small, partly rounded crystals, and irregular opaque minerals.

Most of the rutile from the southern Sangre de Cristo Mountains is derived from the granites and mica schists. Reddish-brown, irregular particles containing cavity and opaque mineral inclusions are of granitic origin. Subrounded grains with partly rounded transparent mineral inclusions are derived from the mica schists.

Titanite—Detrital titanite is pale yellow to yellowish brown, and grains with cloudy interiors are common. It is represented by flattened grains with smooth margins, irregular particles, and a few rhombs. Most of the grains are characterized by incomplete extinction, color change from blue to yellow and red under crossed nicols, and weak pleochroism. Most of the grains are traversed by a network of cracks.

Irregularly shaped particles and rhombs are from granites; flattened, circular grains, many with a network of cracks, are derived from schists.

Feldspars—Three varieties of feldspar, potash, soda, and lime, are represented. Particles are mostly angular. A white, almost opaque alteration material is found along cleavage planes and on the margins of grains. Orthoclase, least numerous of the detrital feldspars, is characterized by cloudy appearance, Carlsbad twinning, large axial angle, and a few inclusions of quartz, mica, and zircon. Microcline, an important constituent of the granites, is recognized by the gridiron structure and the wavy extinction. A few inclusions of iron oxide, muscovite, and zircon were observed. Plagioclase, primarily labradorite, is the chief feldspar in schists. It has well developed albite with Carlsbad twinning, extinction angle of about 30 degrees (according to albite law), and numerous inclusions of zircon and rutile. Some of the fragments disclose undulose extinction and bent lamellae.

SUMMARY

The mineral content of the detritals at the time of weathering from pre-Cambrian rocks in the Southern Sangre de Cristo provenance include an abundance of quartz, hornblende, biotite, and muscovite; smaller quantities of magnetite, ilmenite, epidote, tourmaline, zircon, garnet, titanite and feldspars; and minor quantities of kyanite and rutile. Most of the individual grains, especially those with more than one possible source of derivation, reveal characteristics that distinguish the parent rock.

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FIGS. 1–4, AUGUST, 1948

SEDIMENTS OF OKI BANK IN THE JAPANESE SEA

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ABSTRACT

A large number of samples from Oki Bank in the Japanese Sea show that it is composed of Tertiary diatomaceous earth mantled by a thin layer of sand and mud in which Tertiary and pre-Tertiary gravels are embedded.

INTRODUCTION

There is a conspicuous chain of islands and banks fringing the Japanese Sea north of Honshu, the main island of Japan. At the southwestern end of this chain, about 70 kilometers northeast of Oki Island, is a large submarine mountain called Oki Bank (fig. 1). It is elliptical, 50 kilometers long, 10 kilometers wide, and the relatively flat top is shallower than 500 meters. The shallowest spot at the southeast end is 288 meters deep. A total of 276 samples were taken from the bank by a snapper sampler and

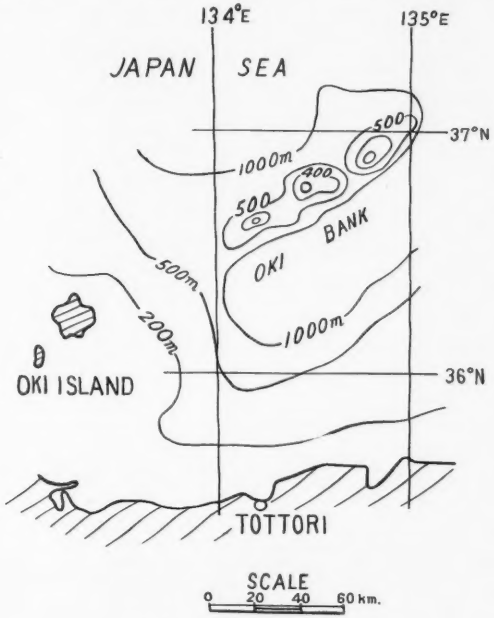

FIG. 1.—Position of Oki Bank.

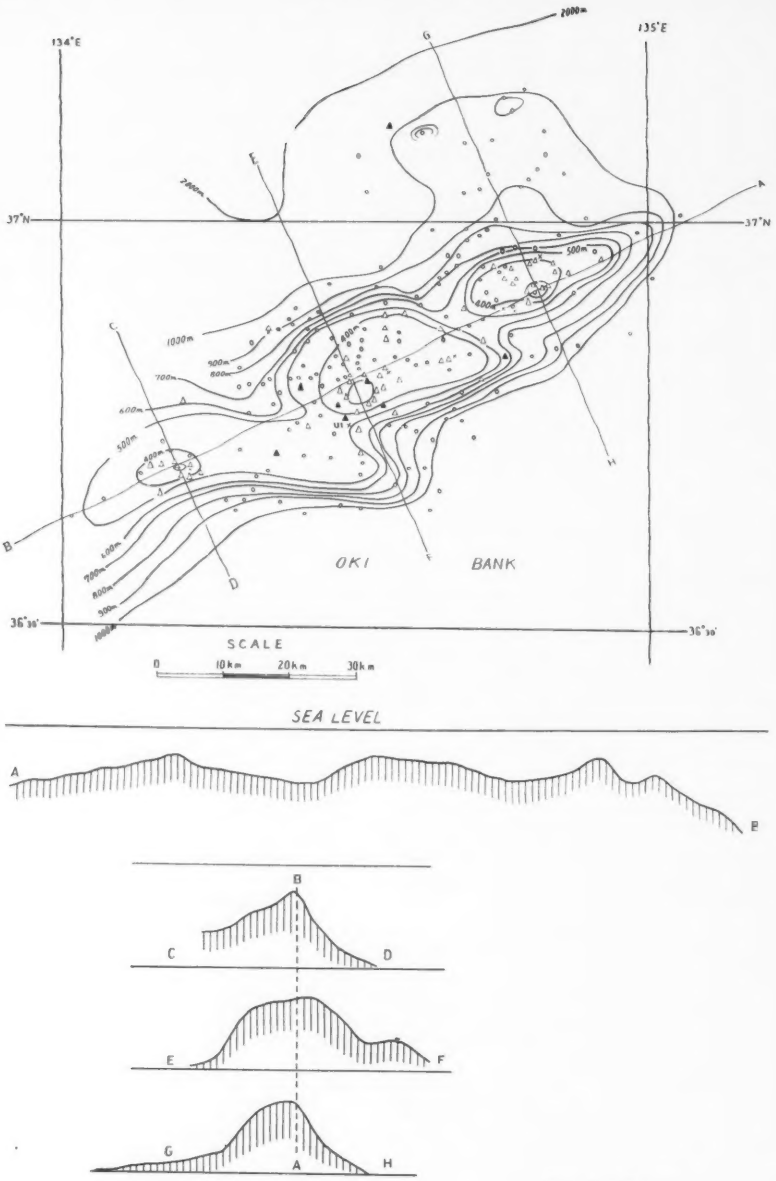

FIG. 2.—See opposite page for description.

one additional sample by dredge. The snapper samples were very small, less than 15 grams, but the dredged sample was about 1000 grams.

The writer wishes to express his sincere thanks to Mr. M. Uda of the Meteorologic Station of Nagasaki who kindly sent the dredged sample and to the members of Suirobu who made the snapper collections available to me.

TABLE 1. *Character of gravel in dredged sample.*

Dimensions, Rock character	Length, cm.	Breadth, cm.	Thickness, cm.	Weight, gm.	Shape	Surface	Encrusting organisms
Greywacke ss.	1.95	1.3	0.7	2.5	round flat	smooth	—
Biotite granite	1.5	1.4	1.1	2.5	angular	irregular	bryozoa
Biotite quartz-porphyry	2.2	1.6	1.2	5.0	subangular	irregular	bryozoa
Pumice	2.2	1.8	1.5	2.5	round	irregular	—

DESCRIPTION OF DREDGED SAMPLE

The one dredged sample was obtained aboard Soyomaru (Station U. 1), on May 29, 1941. Its position was Latitude 36°44′ N, Longitude 134°29′ E, and it was from a depth of 400 meters. In general appearance it was a sandy mud containing gravel and organisms.

The gravels are well water-worn and some of the fragments are heavily encrusted on one side by organisms such as calcareous sponges and bryozoans. These indicate that the gravels were partly buried in the mud and partly exposed. Examination of the gravels under the microscope revealed that they are composed of greywacke, biotite granite, biotite quartz porphyry, and liparite. The dimensions and shapes of the large fragments of each kind of rock are listed in Table 1.

Mechanical analysis was made by sieving 20 grams of the sediment, using the methods of the soil test Committee of the Rail Road Department. The results are shown in Figures 3a and b.

The larger organisms in the bottom samples are as follows:

Pelecypoda. *Pecten* (*Pseudamsium*) *intuscostatum* Yokoyama. (One living young specimen) *Poromya flexuosa* Yokoyama. (Two dead shells.)

Scaphopoda. *Dentalium toyamense* Kuroda and Kikuchi. (A fragment).

Echinoidea. *Leptychaster* sp. (One young specimen).

Siliceous Sponge, Bryozoa, Annelida, Nemathelminthes.

SNAPPER SAMPLES

The snapper samples were collected at 276 stations on the bank by the Suirobu,

FIG. 2.—Bathymetric features of Oki Bank and the stations where the bottom samples were collected.

○ The stations where the bottom samples were collected.
△ The stations where the gravels were exposed on the sea bottom.
▲ The stations where the gravels were buried under mud.
× The stations where organisms were collected.

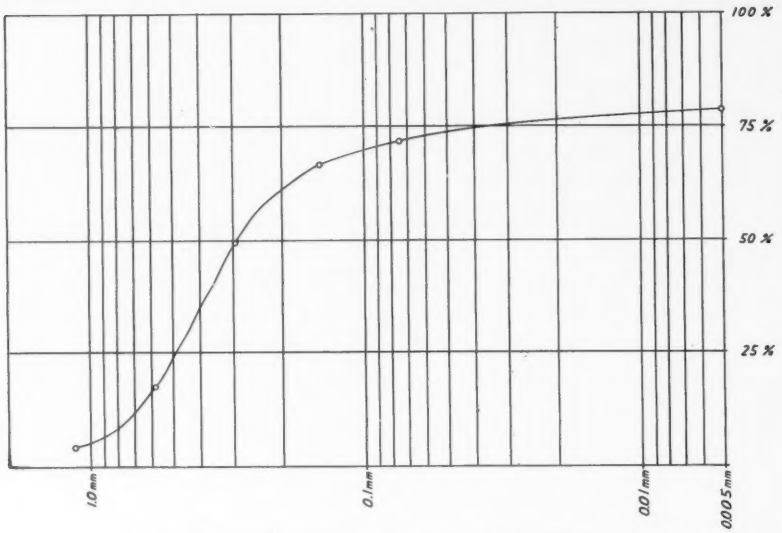

FIG. 3a.—The cumulative curve of the sand dredged from Station U. 1.

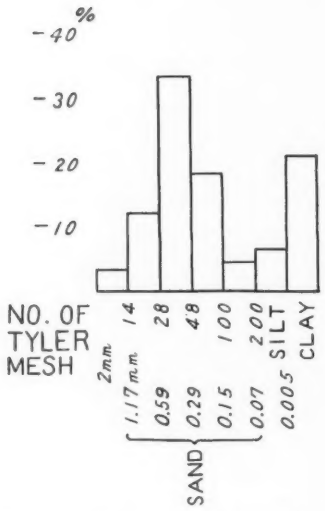

FIG. 3b.—Histogram of the mechanical analysis.

the Hydrographic Department of the Japanese Navy. Only 4 stations are deeper than 1500 meters, one of which, Station 60, is at 1758 meters. Twelve stations are shallower than 300 meters, the shallowest of which, Station 222, is 228 meters.

A rock fragment was collected from Station 91 (36°44′ N, 134°31′ E, 635 meters deep) on the east side of the center of the bank. It is of a yellowish, tuffaceous, diatomaceous earth, 1.3 cm. long, 1.2 cm. wide, 0.7 cm. broad, and weighs 1.0 grams. Observed under the microscope it was found to consist of volcanic glass, biotite, and clay. It contains fossil diatoms, radiolarians, and sponge spicules. The diatoms are *Coscinodiscus* sp., *Cyclotella* sp., *Biddulphia* sp., *Pinnularia* sp. The Radiolaria is *Porodiscus* sp. Rocks of this character are present in the Tertiary formations at Oki Island.

Gravels were obtained from 74 snapper stations and pumice from one station. The depth distribution of stations shal-

TABLE 2. *Depth distribution of snapper samples containing gravel.*

Depth	250–300 m.	300–350 m.	350–400 m.	400–450 m.	450–500 m.	500–550 m.	550–600 m.	600–650 m.
Number of sounding station	12	39	57	28	23	11	12	4
Number of stations where gravels were found	3	20	24	9	8	4	2	1
% of the number of the stations where gravels were found	25%	51%	42%	32%	30%	36%	17%	25%
Stations where gravels encrusted by organisms	1	7	3					
% of the number of gravel stations having attached organisms	33%	35%	12%					

lower than 650 meters where gravels were found is presented in Table 2 and Figures 4a and b. The stations are grouped in 50 meter depth zones. The deepest gravel station is Station 60 (1758 meters). The shallowest is Station 253 (281 m.). It is notable that all of the shallower gravel stations are on the east edge of the bank and all the deep gravel stations are on the west side. The gravels are well water-worn and most of them have an organic encrustation and are presumed to have been buried beneath sediment. Gravels encrusted with organisms and supposed to have been exposed on the floor were found at the following stations: Sta. 130 (932 m.), Sta. 150 (322 m.), Sta. 151 (303 m.), Sta. 146 (361 m.), Sta. 154 (320 m.), Sta. 107 (376 m.), Sta. 168 (284 m.), Sta. 171 (317 m.), Sta. 230 (446 m.), Sta. 261 (352 m.), Sta. 262 (337 m.), Sta. 263 (273 m.). Note that organic encrustations are most common between the depths of 300 and 350 m. The gravels

TABLE 3. *Organisms collected at snapper stations.*

Sta.	N. Lat.	E. long.	Depth	Bottom character	Organisms
9	36°46′08″	134°30′03″	277m.	mud	Bryozoa, porifera
71	36 53 02	134 45 03	458	mud	*Lucina actilineata*
72	36 52 07	134 45 03	468	mud	*Lucina acutilineata*
254	36 54 04	134 47 08	288	sand	*Stylaster* sp.
258	36 54 06	134 48 01	281	sand	Bryozoa
100	36 43 01	134 25 04	473	mud	Ophiuroidea
115	36 46 02	134 28 02	376	gravel	Shark teeth
167	36 46 06	134 29 02	348	mud	Bryozoa
130	36 51 07	134 21 00	932	fine sand	*Stylaster* sp.
197	36 48 02	134 33 08	345	mud	Bryozoa
202	36 49 03	134 39 03	346	gravel	Bryozoa
233	36 40 04	134 13 02	371	mud	*Limopsis crenata*
263	36 56 02	134 46 08	273	gravel	Bryozoa
262	36 55 02	134 46 02	337	gravel	Chiton sp.

are composed of chert at 5 stations, greywacke at 2 stations, and biotite granite at 4 stations. These are all pre-Tertiary sedimentary or igneous rocks. Some of the gravels are composed of quartz-porphyry, probably of Tertiary age.

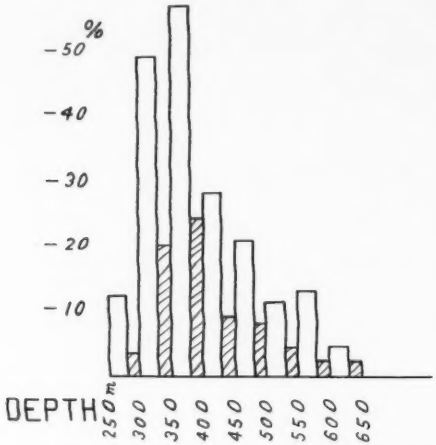

FIG. 4a.—The number of the snapper stations and the number of the stations where gravels were collected in each 50 meter depth zone. White—Snapper station. Black—Station where gravel was collected.

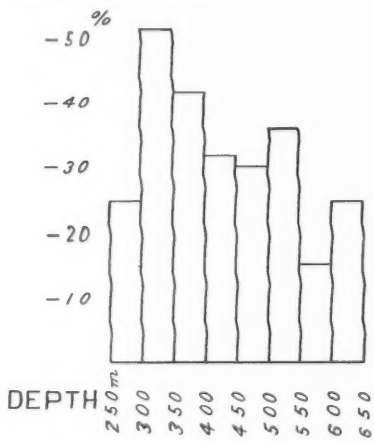

FIG. 4b.—The percentage of the number of the stations where gravels were found to the total number of the stations in each 50 meter depth zone.

Sand and mud associated with the gravel is relatively coarse except at stations on the deep sea bottom. For example, the sand of Station 60 (1758 m.) consists of 0.03 m. diameter grains of volcanic glass, colored minerals, sponge spicules, radiolarians, and diatoms (*Coscinodiscus* sp.).

The position of stations where organisms were obtained are listed in Table 3 showing that the organisms are most abundant in the shallower part of the bank.

CONCLUSIONS

The floor of the bank is composed of soft, tuffaceous, diatomaceous earth. It may be referred to the Tertiary of Oki Island. Overlying this material is a thin layer of gravel embedded in coarse sand and mud. The gravels are widely distributed on and around the bank and have been found as deep as 1760 m. They

are well water-worn and consist of pre-Tertiary rocks such as granite, chert, and greywacke, and Tertiary rocks such as liparite and quartz-porphyry. Organisms found with the sediment include bivalves, deep-sea corals, bryozoans, worms, echinoids, and shark teeth. Some plant material, pine bark, was also found.

The structure and the covering sediments closely resemble those of the other banks of the Japanese Sea which extend in an arc parallel to the trend of the main Japanese Island. Oki Bank appears to be a recently submerged land block which is closely related in stratigraphy and topography to the main Japanese island.

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ITABIRITE OF MINAS GERAES, BRAZIL

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ABSTRACT

The mosaic texture and lack of clastic heavy accessory minerals indicate that the quartzose phase of the itabirite is recrystallized chert rather than clastic quartz.

The term itabirite was originally proposed by Eschwege (1822) for the massive, high grade specular iron ore of pre-Cambrian age in the Minas Geraes province of Brazil. Derby (1910, p. 817) followed common usage in the district, and applied the term to the, ". . . schistose rock composed of granular quartz and scaly hematite . . . ," which is associated with the high grade ores. He states that, "Through variation in the relative proportions of the constituent elements this type of rock grades off on one side to a purely quartzose and on the other side to a purely hematitic phase." Derby (1910, p. 817) does not describe the itabirite very fully, but does refer to it as, "The peculiar iron-bearing quartzite."

Leith and Harder (1911, p. 673) followed Derby's suggestion and refer to the quartzose phase of the itabirite as, "quartzite itabirite" and note that the, "Silica in the itabirite is in the form of sand grains rather than chert." (1911, p. 681)

Harder and Chamberlin (1915, p. 341–378, 385–424) also refer to the quartzose phase of the itabirite as clastic quartz. They considered that the hematite and clastic quartz were derived through the mature weathering of a land surface, but found it difficult to explain the segregation of the iron to form the high grade ore bodies. They concluded that the iron probably was precipitated from solution, perhaps by bacterial action, in relatively clear seas where comparatively little clastic sediment was being deposited.

Perhaps the most significant aspect of the Minas Geraes itabirite, as it has been described, is that the iron oxide seems to be associated with clastic quartz rather than chert. The pre-Cambrian iron formations throughout the world are normally composed of an iron mineral or minerals, such as siderite, greenalite, or iron oxide, associated with large volumes of chert. The pre-Cambrian iron formation in some regions, such as the Marquette district of Michigan contains local clastic quartz beds, but even in these cases chert is the dominant form of silica in the iron formation.

The metamorphic phase of the iron formation in the Lake Superior region is represented locally by a granular, quartzose rock composed of recrystallized chert, which closely resembles sandstone or quartzite. Since the itabirite of Brazil has also been metamorphosed one would expect the original chert to be recrystallized and assume the granular character and grain size of a clastic sediment. This possibility led the writer to examine the numerous specimens of itabirite in the Economic Geology Collections at the University of Wisconsin. The main part of the itabirite suite was collected by E. C. Harder in 1920.

The quartzose phase of the itabirite has the appearance of a fine to medium grained, friable sandstone, but also closely resembles an oxidized phase of the metamorphic iron formation from the Lake Superior region. Thin sections of the itabirite show that the quartz phase is identical with recrystallized chert

from the Marquette district of Michigan. The grains have the mosaic pattern characteristic of recrystallized chert and not a single grain was observed that even remotely suggested clastic origin. Clastic quartz has invariably associated with it a group of minor accessory minerals, such as ilmenite, magnetite, tourmaline, garnet, rutile, and the ubiquitous zircon. These accessory minerals have been used by many workers to determine the provenance of sediments, to correlate sediments, and to help unravel the paleogeography at the time of deposition. The writer has never examined clastic quartz, which did not contain one or more of the accessory minerals. On the other hand the cherty iron formation of the Lake Superior region contains no clastic heavy accessory minerals, except locally where clastic quartz is present. Thus it is possible to distinguish recrystallized chert from sandstone or quartzite by determining the presence or absence of clastic heavy accessory minerals.

Twenty samples of the itabirite from the Harder collection were crushed and heavy accessory mineral separations made according to standard procedure. Examination of the slides revealed no zircon or other clastic heavy minerals. This is taken to indicate that the quartz of the itabirite is recrystallized chert and not clastic quartz. The iron formation of the Minas Geraes region is therefore very similar to the recrystallized, metamorphic phase of the Lake Superior region and may well be of the same origin.

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AUGUST, 1948

REVIEWS

V. L. BOSSAZZA. *The Petrography and Petrology of South African Clays*, 1946, Percy Lund Humphriies and Co., Ltd., London and Bradford, England. Price 2 pounds, 2 shillings.

This work on South African Clays consists of three parts. Part 1 considers the "Petrography of Clays" in eight chapters, as follows:

(1) Ultimate chemical composition, including minor constituents.
(2) Size distribution of clays.
(3) Geochemistry of clays.
(4) Microscopic examination.
(5) Mineral analyses.
(6) The clay minerals.
(7) Water and clay.
(8) Reactions between organic compounds and clays.

The reviewer does not consider that part 1 contributes much to a better understanding of clays. This part of the work is largely a compilation from and a summary of the contributions of other students of clays and clay minerals. Analyses presented by the author are mostly from South Africa and are new.

Part 2 is concerned with "Family Groups of Clays" and these are considered in Chapters 9 to 13 as follows:

(9) Methods of classification.
(10) Alumino-silicate hydrates
(11) Hydrates of alumina and iron with kaolinite and other minerals.
(12) Hydrous silicates of alumina, iron, calcium, magnesium, potassium, and sodium.
(13) Silcretess (silica hydrate rocks).

The titles of the chapters indicate matters therein considered and there is generally excellent adherence to the subject. There is much reference to the work of other students of clays and clay minerals, but the matter presented in Part 2 is largely that of the author. Following Lyon (The Nature and Properties of Soils, 1943) he describes the hydroxides of iron and alumina as clays. The reviewer fails to see any good reason for such inclusion.

Part 2 considers the "Petrology of Clays" in chapters 14 to 21 as follows:

(14) The weathering of rocks.
(15) Weathering of various rock types.
(16) Transportation
(17) Sedimentation, compaction and the time element.
(18) Residual clay deposits.
(19) Deposits of transported clays.
(20) Clays formed under marine and estuarine conditions.
(21) Transporting deposits, more recent in age and not correlatable with others.

The matter presented in chapter 14 adds little to what is already known in that it is largely compiled from the works of others. The matter presented in chapters 15 to 21 is largely the work of the author.

The list of references numbers 219. There are 15 text figures, and the index is good. There are several errors of spelling and some of punctuation. The printing has been done by the Replica Process.

The reviewer did not learn a great deal from this book in the way of general knowledge. Data relating to South African clays are present in abundance. The book doubtless will be of much service to geologists and others interested in the characters and utilization of the South African clays.

W. H. TWENHOFEL

CHAMBERS. *Mineralogical Dictionary*, 1948. Chemical Publishing Company, Brookline, New York. Price $4.75.

This book defines over 1400 mineralogical terms and gives the chemical composition, crystal forms, physical and chemical properties, occurrences and uses of all minerals described. There are 40 plates giving colored illustrations of 122 minerals and rocks.

This little book, which is sufficiently small to be easily carried in the pocket of one's coat, should be very useful to all interested in minerals.

W. H. TWENHOFEL

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